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12/01/97

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PTO/SB/05 (12/97)

Approved for use through 09/30/00. OMB 0651-0032
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FEE TRANSMITTAL FOR FY 2000**TOTAL AMOUNT OF PAYMENT (\$)** 2880.00**Complete if Known:**

Application No. Not Yet Assigned
 Filing Date Not Yet Assigned
 First Named Inventor Kathrin Berkner, et al.
 Group Art Unit Not Yet Assigned
 Examiner Name Not Yet Assigned
 Attorney Docket No. 074451.P110

METHOD OF PAYMENT (check one)

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FEE CALCULATION**1. BASIC FILING FEE**

Large Entity		Small Entity		Fee Description	Fee Paid
Code	Fee (\$)	Code	Fee (\$)		
101	690	201	345	Utility application filing fee	<u>690.00</u>
106	310	206	155	Design application filing fee	<u> </u>
107	480	207	240	Plant filing fee	<u> </u>
108	690	208	345	Reissue filing fee	<u> </u>
114	150	214	75	Provisional application filing fee	<u> </u>
SUBTOTAL (1) \$					<u>690.00</u>

2. EXTRA CLAIM FEES

			Extra Claims	Fee from below	Fee Paid
Total Claims	<u>120</u>	- 20** =	<u>100</u>	X <u>18.00</u>	= <u>1800.00</u>
Independent Claims	<u>8</u>	- 3** =	<u>5</u>	X <u>78.00</u>	= <u>390.00</u>
Multiple Dependent					= <u> </u>

**Or number previously paid, if greater; For Reissues, see below.

Large Entity		Small Entity		Fee Description	Fee Paid
Code	Fee (\$)	Code	Fee (\$)		
103	18	203	9	Claims in excess of 20	<u> </u>
102	78	202	39	Independent claims in excess of 3	<u> </u>
104	260	204	130	Multiple dependent claim, if not paid	<u> </u>
109	78	209	39	**Reissue independent claims over original patent	<u> </u>
110	18	210	9	**Reissue claims in excess of 20 and over original patent	<u> </u>
SUBTOTAL (2) \$					<u>2190.00</u>

01/10/2000

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PTO/SB/17 (6/99)

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FEE CALCULATION (continued)**3. ADDITIONAL FEES**

<u>Large Entity</u>		<u>Small Entity</u>		<u>Fee Description</u>	<u>Fee Paid</u>
<u>Code</u>	<u>Fee (\$)</u>	<u>Code</u>	<u>Fee (\$)</u>		
105	130	205	65	Surcharge - late filing fee or oath	_____
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	_____
139	130	139	130	Non-English specification	_____
147	2,520	147	2,520	For filing a request for reexamination	_____
112	920*	112	920*	Requesting publication of SIR prior to Examiner action	_____
113	1,840*	113	1,840*	Requesting publication of SIR after Examiner action	_____
115	110	215	55	Extension for response within first month	_____
116	380	216	190	Extension for response within second month	_____
117	870	217	435	Extension for response within third month	_____
118	1,360	218	680	Extension for response within fourth month	_____
128	1,850	228	925	Extension for response within fifth month	_____
119	300	219	150	Notice of Appeal	_____
120	300	220	150	Filing a brief in support of an appeal	_____
121	260	221	130	Request for oral hearing	_____
138	1,510	138	1,510	Petition to institute a public use proceeding	_____
140	110	240	55	Petition to revive unavoidably abandoned application	_____
141	1,210	241	605	Petition to revive unintentionally abandoned application	_____
142	1,210	242	605	Utility issue fee (or reissue)	_____
143	430	243	215	Design issue fee	_____
144	580	244	290	Plant issue fee	_____
122	130	122	130	Petitions to the Commissioner	_____
123	50	123	50	Petitions related to provisional applications	_____
126	240	126	240	Submission of Information Disclosure Stmt	_____
581	40	581	40	Recording each patent assignment per property (times number of properties)	_____
146	690	246	345	For filing a submission after final rejection (see 37 CFR 1.129(a))	_____
149	690	249	345	For each additional invention to be examined (see 37 CFR 1.129(a))	_____
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Serial/Patent No.: **** Filing/Issue Date: ****
Client: Ricoh
Title: WAVELET-BASED IMAGE PROCESSING PATH

BSTZ File No.: 074451.P110 Atty/Secty Initials: MJM/mzb
Date Mailed: 09/08/00 Docket Due Date: ****

The following has been received in the U.S. Patent & Trademark Office on the date stamped hereon:

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| <input checked="" type="checkbox"/> Application - Utility (<u>76</u> pgs., with cover and abstract) | <input type="checkbox"/> Information Disclosure Statement & PTO 440 (____ pgs) | <input type="checkbox"/> Check No. _____ |
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| <input checked="" type="checkbox"/> Drawings: <u>11</u> # of sheets includes <u>13</u> figures | <input checked="" type="checkbox"/> Fee Transmittal, in duplicate | |

☐ Other: _____

UNITED STATES PATENT APPLICATION

for

WAVELET-BASED IMAGE PROCESSING PATH

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File No.: 74451.P110

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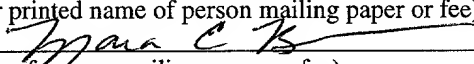
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WAVELET-BASED IMAGE PROCESSING PATH**FIELD OF THE INVENTION**

5 The present invention relates to the field of image processing; more particularly, the present invention relates to a wavelet-based image enhancement system.

BACKGROUND OF THE INVENTION

10 Image processing has many applications. One such application is in a digital copier. A digital copier typically has different modes for copying text or an image. The different modes, text or letter mode vs. photo mode, include special image processing techniques such as sharpening or smoothing of the scanned document, thinning of text, despeckeling, etc. Problems arise if the copied document has text and image content. In order
15 to apply different techniques to text and image regions of a document, a segmentation of the document or a classification of the pixel of the scanned document is needed. Without out this classification, an oversmoothing of text in the photo-mode may occur and an enhancement of halftone noise in the text mode may occur. A consequence of this enhancement of halftone
20 noise in the text mode can be the creation of severe Moire patterns after resolution reduction. Such artifacts are observed in many current digital

copiers. A typical imaging path for digital gray scale copier is demonstrated in Figure 1.

Referring to Figure 1, a scanned image 100 is input into processing block 101, which changes gray values in the scanned image to compensate for scanner bias through lookup tables or other point operation (e.g., gamma correction). Next, different regions in the scanned image are classified (e.g., text, halftone, continuous tone, etc.) (processing block 102). The pixels are then filtered by processing block 103 depending on the classified pixel. Such filtering may include smoothing or sharpening of pixels based on their classification. After filtering, the pixels undergo up and/or downsampling by processing block 104. The pixels may also be subjected to resizing for enlarging/reducing. Next, the gray values of the pixels are changed through look up tables or other point operation (e.g., gamma correction) to compensate for printer bias (processing block 105). Once changing of the gray values has been done, halftoning is performed on the pixels (processing block 106). For non-copier applications, halftoning might be replaced with another output formatting step, the result of which is processed image 107.

Single components of the digital imaging copier path are prior art, such as contrast enhancement of the scanned image or halftoning for

5 1998 to Vuylsteke and Schoeters. There are also publications on image enhancement with wavelets that include denoising and contrast enhancement. For example, Zong, Laine, Geiser, and Wilson, "De-Noising and Contrast Enhancement via Wavelet Shrinkage and Non-linear Adaptive Gain," Proceedings of the SPIE, Vol. 2762, pgs. 566-574, 1996. Image
10 enhancement using the Laplacian pyramid to add high frequency content to the image is also known. For example, see U.S. Patent No. 5,717,789, entitled "Image Enhancement by Non-linear Extrapolation in Frequency Space," issued February 1998 to Anderson and Greenspan.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood more fully from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however, should not be taken
5 to limit the invention to the specific embodiments, but are for explanation and understanding only.

Figure 1 illustrates a prior art image processing path for a grayscale copier.

10

Figure 2A is a block diagram of one embodiment of a system having a wavelet-based image processing path.

Figure 2B is a block diagram of one embodiment of a digital copier.

15

Figure 2C is a block diagram of one embodiment of a wavelet-based processing path for a digital copier.

Figure 3 illustrates a classifier for use in a copier or printer.

20

Figure 4A illustrates the formation of wavelet coefficients of a halftone and diagonal line pattern using a 2D Haar wavelet transform .

5

10

Figure 7 is a block diagram of one embodiment of a copier.

Figure 8 is a block diagram of one embodiment of a computer system.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

A method for processing an image and apparatus for doing the same are described. In the following description, numerous details are set forth in order to provide a thorough understanding of the invention. It will be
5 apparent, however, to one skilled in the art, that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form, rather than in detail, in order to avoid obscuring the present invention.

Some portions of the detailed descriptions which follow are presented
10 in terms of algorithms and symbolic representations of operations on data bits within a computer memory. These algorithmic descriptions and representations are the means used by those skilled in the data processing arts to most effectively convey the substance of their work to others skilled in the art. An algorithm is here, and generally, conceived to be a self-
15 consistent sequence of steps leading to a desired result. The steps are those requiring physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It has proven convenient at times, principally for

reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like.

It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise as apparent from the following discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing" or "computing" or "calculating" or "determining" or "displaying" or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission or display devices.

The present invention also relates to apparatus for performing the operations herein. This apparatus may be specially constructed for the required purposes, or it may comprise a general purpose computer selectively activated or reconfigured by a computer program stored in the computer. Such a computer program may be stored in a computer readable

storage medium, such as, but is not limited to, any type of disk including floppy disks, optical disks, CD-ROMs, and magnetic-optical disks, read-only memories (ROMs), random access memories (RAMs), EPROMs, EEPROMs, magnetic or optical cards, or any type of media suitable for storing electronic
5 instructions, and each coupled to a computer system bus.

The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized
10 apparatus to perform the required method steps. The required structure for a variety of these systems will appear from the description below. In addition, the present invention is not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the
15 invention as described herein.

A machine-readable medium includes any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium includes read only memory ("ROM"); random access memory ("RAM"); magnetic disk storage media;

optical storage media; flash memory devices; electrical, optical, acoustical or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.); etc.

5 Overview

The processing described herein provides for image processing between scanned (or otherwise sensed) digital images and digital images for display or printing. This image processing might be in a digital image in, digital image out device such as, for example, a printer controller (e.g., for a network) or performed in a general purpose computer. The image processing described herein might be combined with an analog input device in, for example, a scanner or digital camera, with a print engine in a printer or with another output device, or with both an input and output device, for example in a digital copier, facsimile machine or multifunction machine.

The wavelet-based image processing described herein may be used to compensate for differences between input and output systems. Some image in and image out systems have matched input and output devices that require little or no image processing between input and output for particular types of images. For example, some video cameras and video displays are

well matched and good results for images of natural scenes require little or no intermediate processing. In contrast, some systems have dissimilar input and output devices or complex/compound image types where significant processing is required. For example, an input device might require less

5 noise, higher sharpness and/or a different size/scale than the input device provides. Additionally different images or different positions in the same image might have different enhancement. The wavelet-based image processing described herein may be used to process an image from an input system (e.g., device) so that it "matches" the output system (e.g., device).

10

Overview of a Wavelet-based Image Processing System

A wavelet-based imaging path for a digital copier or multifunction machine having automatic adaption of image processing routines to various characteristics in the image such as, for example, text and background is

15 described.

The wavelet-based image processing may occur after non-wavelet-based processing blocks or modules and/or before other non-wavelet-based processing blocks or modules. Figure 2A is a block diagram of a system having a wavelet-based image processing path. Referring to Figure 2A, an

image source 250 generates image data. Image source 250 may comprise, for example, a digital camera, scanner, a network or channel, storage, etc. Then processing logic, optionally, changes gray values through look up tables (e.g., gamma correction) (processing block 251). Alternatively, the image

5 data may be subjected to a point operation. Afterwards, processing image data is received by wavelet-based image processing block 252 for wavelet-based processing. After wavelet based processing, processing logic optionally changes the gray values of the image data through look up tables (e.g., gamma correction) or, alternatively, a point operation. Next,

10 processing logic performs halftoning on the image data or some other form of preparation for output (processing block 254) and delivers the processed image data to an image distinction 255. Image distinction 255 may comprise, for example, a printer, print engine, display, network or channel, or storage.

Figure 2B is a block diagram of a copier. Referring to Figure 2B,

15 processing logic receives a scanned image 280, and then, optionally, changes gray values in the scanned image 200 through look up tables (e.g., gamma correction) (processing block 281). Alternatively, scanned image 280 may be subjected to a point operation. Afterwards, processed image data is received by wavelet-based image processing block 252 for wavelet-based processing.

After wavelet-based processing, processing logic optionally changes the gray value of the image data through look up tables (e.g., gamma correction) or, alternatively, a point operation. Next processing logic performs halftoning on the image data or some other form of preparation for output (processing block 254), thereafter outputting processed image 285.

Figure 2C is a block diagram of one embodiment of a wavelet-based image processing path for a digital copier. In one embodiment, this image processing path replaces processing blocks 102-106 in Figure 1 in a copier or other image processing device. The processing may be performed by processing logic that may comprise hardware, software or a combination of both.

Referring to Figure 2C, forward wavelet transforms block 201 performs a wavelet transform on the scanned image to create a set of coefficients. The coefficients may be optionally sent to wavelet-based classifier processing block 202A, which classifies the coefficients.

Alternatively, image data may be directly input to a non-wavelet-based classifier block 202B. The classifier information output from classifier processing blocks 202A and 202B may be used in cooperation with

processing block 203-206, 209, 210 and 202C. These processing blocks are described below.

Processing logic performs thresholding on the coefficients output from wavelet transform block 201 (processing block 203). After
5 thresholding, processing logic rescales coefficients (processing block 204). Next, processing logic filters coefficients (processing block 205).

After filtering coefficients, processing logic may optionally perform upsampling or downsampling (processing block 206). Subsequently, processing logic performs an inverse wavelet transform on the coefficients
10 (processing block 207). In an alternative embodiment, processing logic performs an inverse wavelet transform that includes upsampling and/or downsampling (processing block 208). Note that if processing logic performs an inverse wavelet transform in combination with up/downsampling (i.e., processing block 208), the processing block 206 is
15 not performed.

After performing an inverse transform, processing logic changes gray values on the image data through a look up table or other point operation (e.g., gamma correction) (processing block 209). Processing logic then performs halftoning on the image data (processing block 210). The output of

halftoning block 210 is a processed image 220. Note that processing blocks 209 and 210 are not performed in the wavelet domain.

The use of signal-adaptive nature of wavelet domain image processing, including a description of each of these blocks follows.

5

Critically Sampled or Overcomplete Discrete Wavelet Decomposition

Initially, in the image processing path, forward wavelet transform block 201 performs a wavelet decomposition on the scanned image up to a chosen level L . L may be any number of levels, but 2 or 3 levels is sufficient for many applications. This transform may be critically sampled or overcomplete. Besides overcomplete (fully redundant) and critically sampled wavelet transforms, a transform with reduced redundancy or a complex transform could also be used. An example for reduced redundancy is the computation of all phases of the critically sampled wavelet transform at the first level of resolution and only some of the phases, such as every other phase at the second level of resolution (see Selesnik, I. W. "Smooth Wavelet tight Frames with Limited Redundancy," Technical report, Dept. Electrical Engineering, Polytechnic University, Brooklyn, NY, August 1999). Alternatively, the phases could be chosen dynamically, e.g., by selecting

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those that contain the most energy. For example, see Coifman, R. R.,
Donoho, D. L. "Translation-invariant De-noising," in *Wavelets and Statistics*
(Editor A. Antoniadis), Springer Lecture Notes, Springer-Verlag, 1995.

Complex transforms compute real and imaginary parts wavelet coefficients,
5 which results in a redundancy factor of two. The imaginary parts contain
phase information on an image region. For example, see Kingsbury, N. "The
dual-tree complex wavelet transform: a new efficient tool for image res-
toration and enhancement," Proceedings European Signal Processing Conf.,
1998, pp. 319-322.

10 If the image is given by $N \times N$ data points then, when using a critically
sampled wavelet transform for L levels, the decomposition is also given by
 $N \times N$ data points, namely wavelet and scaling coefficients. When using the
overcomplete wavelet transform for L levels, the decomposition is given by
 $(3L+1)N \times N$ data points.

15 In both cases, wavelet coefficients d_l for levels $l=1$ to L and scaling
coefficients c_L at the coarsest level have to be stored. In one embodiment, an
overcomplete Haar wavelet transform is used. An example of a 1D critically
sampled Haar transform (without L_2 - normalization, low pass = $a + b$, high
pass = $a - b$; ignore boundaries) is given below:

Table 1

input	low pass output	high pass output
5	12	-2
7		
1	2	0
1		
8	15	1
7		

An example of overcomplete Haar transform is as follows:

Table 2

input	low pass output	high pass output
5	12	-2
7		
1	8	6
1	2	0
1	9	-7
8	15	1
7		

Examples of filter coefficients for different wavelet systems are as follows:

Haar : $\begin{bmatrix} 1 & 1 \end{bmatrix} \begin{bmatrix} 1 & -1 \end{bmatrix}$ normalized by $1/\sqrt{2}$.

2-6 : $\begin{bmatrix} 1 & 1 \end{bmatrix} \begin{bmatrix} -1/8 & -1/8 & 1 & -1 & 1/8 & 1/8 \end{bmatrix}$ normalized by $1/\sqrt{2}$.

5-3 : $\begin{bmatrix} -1/4 & 1/2 & 3/2 & 1/2 & -1/4 \end{bmatrix} \begin{bmatrix} 1/4 & -1/2 & 1/4 \end{bmatrix}$ normalized by $1/\sqrt{2}$.

2-10 : $\begin{bmatrix} 1 & 1 \end{bmatrix} \begin{bmatrix} 3 & 3 & -22 & -22 & 128 & -128 & 22 & 22 & -3 & -3 \end{bmatrix} / 128$ normalized by $1/\sqrt{2}$.

9-7 : $\begin{bmatrix} 0.037828 & -0.023849 & -0.110624 & 0.377402 & 0.852699 & 0.377402 \\ -0.110624 & -0.023849 & 0.037828 \end{bmatrix}, \begin{bmatrix} 0.064539 & -0.040689 & -0.418092 \\ 0.788486 & -0.418092 & -0.040689 & 0.064539 \end{bmatrix}$

daub6 : $\begin{bmatrix} 0.0352 & -0.0854 & -0.1350 & 0.4599 & 0.8069 & 0.3327 \end{bmatrix}, \begin{bmatrix} -0.3327 & 0.8069 \\ -0.4599 & -0.1350 & 0.0854 & 0.0352 \end{bmatrix}$.

The forward low pass and high pass filters are specified. For symmetric biorthogonal filters, the inverse filters are the forward filters with

- 5 alternating signs changed starting with the second and reversed. For example for the 2-6 filter:

Forward low pass $\begin{pmatrix} 1 & 1 \end{pmatrix} 1/\sqrt{2}$

Forward high pass $\begin{pmatrix} -1/8 & -1/8 & 1 & -1 & 1/8 & 1/8 \end{pmatrix} 1/\sqrt{2}$

Inverse low pass $\begin{pmatrix} -1/8 & 1/8 & 1 & 1 & 1/8 & -1/8 \end{pmatrix} 1/\sqrt{2}$

- 10 Inverse high pass $\begin{pmatrix} -1 & 1 \end{pmatrix} 1/\sqrt{2}$

This selection of filters covers the characteristics for the most widely used wavelet families (orthogonal, biorthogonal, symmetric, even-length,

odd-length). The transform may also be any LeGaul-Tabatabai biorthogonal transform.

For a two dimensional wavelet transform, both low pass and high pass filters are applied horizontally and vertically. The four resulting

5 subbands are:

	<u>Subband</u>	<u>horizontal filter</u>	<u>vertical filter</u>
	LL	low pass	low pass
	HL	high pass	low pass
	LH	low pass	high pass
10	HH	high pass	high pass

Multiscale Sharpening, Smoothing and Denoising

In one embodiment, thresholding and multiplication are performed
 15 on the wavelet coefficients to achieve denoising, sharpening, and smoothing. A criterion dictates whether thresholding or multiplication are applied. In one embodiment, the criterion comprises the magnitude of wavelet coefficients. Alternatively, a classifier could be used to indicate whether to apply thresholding and/or multiplication.

20

Denoising by Thresholding

Denoising may be performed by setting all coefficients below a given threshold to zero. This technique is known as hard-thresholding and is well-

known in the art. As an alternative, soft-thresholding, e.g., shrinking the coefficients above the threshold toward zeros by the amount of the threshold can also be considered. Such a technique may be advantageously used for critically sampled and overcomplete wavelet decompositions, and is

- 5 described in Donoho, "Denoising by Soft-Thresholding", IEEE Transactions on Information Theory, 41(3): 613-627, 1995. The threshold may be one that is calculated for the presence of additive Gaussian White noise in an image. This threshold depends only on the size of the data and the variance of the noise which is estimated from the wavelet coefficients using a well-known
- 10 procedure (e.g., statistical estimation of variance). Other choices of threshold selection may be used. These may be calculated from a series of test images.

- There are additional strategies for thresholding available. There may be a global threshold or different thresholds for different levels of
- 15 decomposition or different bands (LH, HL, HH). The thresholds may be set manually. Thresholds may depend on one or more of the following parameters:

1. Standard deviation or median of absolute values of coefficients in one region (e.g., HH coefficients at level 1) (global threshold)

2. Standard deviation or median of absolute values of HH coefficients at each level (level-dependent threshold)
3. Standard deviation or median of absolute values of LH/HL/HH coefficients at first level (band-dependent threshold). For the example of two levels of decomposition three thresholds are chosen
4. Standard deviation or median of absolute values of LH/HL/HH coefficients at each level (level-band-dependent threshold). For the example of two levels of decomposition, six thresholds are chosen.
5. Manually set thresholds (global, level-dependent, level-band dependent) using controls that are part of the user interface of the device.
6. Local thresholding by computing local variances or medians of coefficients in between a band.
7. Given classifier: select for each strategy (global, level-dependent, level-band dependent) a number of thresholds corresponding to the number of classes. Then use those classifier-dependent thresholds.

Laplacian based techniques applied to wavelets do not perform the superior wavelet-only denoising. It is important to note that wavelet denoising techniques do not apply to Laplacian pyramid decompositions.

Laplacian pyramid decompositions can be used only for systems where inferior or no denoising is acceptable.

Rescaling of Coefficients

- 5 After any denoising is completed, the wavelet coefficients that are non-zero are modified for the purpose of sharpening or smoothing.
- In one embodiment, sharpening or smoothing of the image is obtained by multiplication of wavelet coefficients with a level-dependent parameter $\mu_j > 0$. For sharpening, the high frequency bands should be multiplied with a
- 10 larger factor than the low frequency bands, whereas for smoothing the low frequency bands should be multiplied with larger factors than the high frequency bands. One way to obtain this rescaling is to multiply the coefficients at level j with $\mu_j = R \cdot 2^{\alpha j}$. The parameter R functions as a renormalization factor for preserving the global energy of coefficients and α
- 15 is the parameter that determines the degree of sharpening ($\alpha < 0$) or smoothing ($\alpha > 0$). For more information, see U.S. Patent Application Serial No. 09/467,544, entitled "Multiscale Sharpening and Smoothing With Wavelets," filed December 10, 1999, assigned to the corporate assignee and incorporated herein by reference. There are many choices for the parameter

R that depend on how the energy of an image is measured. One way would be to preserve the L^2 norm $\sqrt{\sum_{i,j} |x_{i,j}|^2}$ of the image before and after rescaling,

i. e. compute R with

$$R^2 = \left(\sum_{j,k} |d_{j,k}|^2 \right) / \left(\sum_{j,k} |\mu_j d_{j,k}|^2 \right)$$

- 5 If the scanned image is assumed to have a Hoelder regularity of γ (typically $\gamma \geq 1$), an approximation of R^2 can be obtained by the following estimate.

$$R^2 = \left[\frac{2^{(L+1)2\gamma} - 2^{2\gamma}}{2^{2\gamma} - 1} \right] / \left[\frac{2^{(L+1)2(\gamma+\alpha)} - 2^{2(\gamma+\alpha)}}{2^{2(\gamma+\alpha)} - 1} \right]$$

- This approximation can be computed a-priori and does not depend on the
10 actual values of wavelet coefficients.

Instead of using the L^2 norm, there are other choices for the norm.

Using the theory of Besov space, it is possible to preserve a specific Besov norm of the image. This norm is defined as a weighted sum of wavelet coefficients. The parameter R can be computed as

$$15 \quad R^q = \left(\sum_j 2^{j(\alpha+q+1/2)} \left(\sum_k |d_{j,k}|^p \right)^{q/p} \right) / \left(\sum_j 2^{j(\alpha+q+1/2)} \left(\sum_k |\mu_j d_{j,k}|^p \right)^{q/p} \right)$$

for $0 < p, q < \infty$.

For $p, q = \infty$, the term $\left(\sum |\dots|^s\right)^{1/s}$ in the previous equation is substituted by

$$\sup |d_{j,k}|.$$

In one embodiment, the choice of the parameters α and R can be
 5 controlled by the user interface of a device, giving the user the opportunity
 to select more/less sharpening, or more/less smoothing. This
 parameterization of sharpening and smoothing allows a fine graduation of
 degrees of enhancement.

As shown in Figure 2 information obtained from a classifier can be
 10 used to determine different parameter α_i , R_i for different classified areas A_i
 in the image.

Filtering of Coefficients

The frequency content of a single subband at a specific level of
 decomposition can be modified by a filtering of that subband. For example,
 15 additional sharpening of the image could be performed by filtering the LL
 component at the largest level of decomposition with a sharpening filter. In
 a similar way, additional smoothing could be performed by applying a

smoothing filter to the LL component. Another possibility is to remove periodic patterns in a specific band by applying a special filter (e.g., a bandpass or notch filter) to that specific band/component of the wavelet decomposition. Thus, a formulation filter is applied in the wavelet domain (e.g., the LL domain) that is equivalent to a larger filter in the pixel domain.

A filter may be used that is suited to reduce or remove special periodicities out of the image. The output of this filter may be used to select different denoising thresholds for halftone and text regions. Periodicity detection can be done with autocorrelation or similar functions. For example,

$$f_i^j = \frac{1}{2}(|x_i - x_{i-j}| + |x_i - x_{i+j}|)$$

or

$$f_i^j = \sqrt{\frac{1}{2}((x_i - x_{i-j})^2 + (x_i - x_{i+j})^2)}$$

15 .

There is periodicity with period 2 at location i if

$$f_i^2 < f_i^1$$

There is periodicity with period 3 at location i if

$$f_i^3 < f_i^1$$

- In some applications, the period (of the periodicity) is known. The
 5 period might be determined from the screen size of a halftoned original to
 be copied and the resolution of the copier's scanner. For example, consider a
 period of 3. Small amplitude wavelet coefficients might be filtered in one
 dimension by

$$d_i^{\text{filtered}} = \frac{(d_{i-1} + d_i + d_{i+1})}{3}$$

- 10 For the overcomplete Haar at level 1 (and no adaptive processing
 such as denoising), this is equivalent to the linear filter $[1 \ 2 \ 2 \ 1]$ in the spatial
 domain.

A two dimensional example is

$$d_i^{\text{filtered}} = 1/9 \begin{pmatrix} d_{i-1,j-1} + d_{i,j-1} + d_{i+1,j-1} + \\ d_{i-1,j} + d_{i,j} + d_{i+1,j} + \\ d_{i-1,j+1} + d_{i,j+1} + d_{i+1,j+1} \end{pmatrix}$$

- 15 For the overcomplete Haar at level 1 this is equivalent to the
 following linear filter in the pixel domain.

$$\begin{bmatrix} 1 & 2 & 2 & 1 \\ 2 & 4 & 4 & 2 \\ 2 & 4 & 4 & 2 \\ 1 & 2 & 2 & 1 \end{bmatrix}$$

Similar 1x5 or 5x5 filters might be used for period 5. When even symmetric wavelet filters are used, even period periodicities are removed easily by the wavelet and extra processing is typically only desired for odd periods.

Use of a Classifier and an Exemplary Classifier

In one embodiment, denoising, sharpening and smoothing of wavelet coefficients is controlled using a classifier. A classifier could be computed based on information extracted from the wavelet coefficients or from some other information source, e.g. the image pixels (Figure 2).

As a decision making step classification is part of a segmentation process that decomposes an image into various components.

Classification or segmentation can be used for many things in a system. It can be used to control one or more of: de-noising, sharpening/smoothing, upsampling/downsampling, change of gray values through lookup table (e.g. gamma correction), halftoning, under-color

removal and/or image compression. Non-wavelet based filtering methods may have a single filter that performs denoising and sharpening/smoothing, and classification would select between different filters. With wavelet-based processing, not only are different parameters used for denoising and sharpening/ smoothing, but also different scales or different wavelet subband may use different parameters. This flexibility is an advantage of wavelet based processing. Having classification only control desired parameters reduces the effect of classification errors. For example for denoising and sharpening/smoothing in one system, perhaps only de-noising is controlled by classification or denoising at the first transform level. In another system, perhaps denoising and sharpening/ smoothing at the first two transform levels are affected by classification.

Regardless of the source of the classification, the result can be used for a variety of things including: setting smoothing parameters, setting sharpening parameters, choosing an "ordinary" linear filter for sharpening or smoothing, controlling the under color removal process in color copiers/printers, as an input to a document classification algorithm, as an input to a compression algorithm (like JBIG 2), as a way to control a halftoning algorithm (or to turn off halftoning for certain image types switch

between error diffusion and ordered dither). For example, when performing under color removal, one classifier may be as follows:

- 5 classify as text or line \rightarrow black = min (cyan, magenta, yellow)
- classify as not text or line \rightarrow black = α min (cyan, magenta, yellow) where $0 < \alpha < 1$, for example $\alpha = 0.75$

10 In a compression framework, JBIG2 and MRC use classification in the sense that the encoder must decide how to classify, but no explicit classification scheme is specified (ISO/IEC 16485: Information technology - Mixed Raster Content (MRC)). These methods could use a wavelet-based classifier in the encoder. Such a classifier is shown in Figures 3A-3C.

Classifiers can distinguish between a variety of different image area types:

- text and line art versus other
- black and white text versus colored or gray text
- 15 • text with patterned backgrounds versus text on plain backgrounds
- text of various sizes
- halftone versus other
- gathered dot halftones versus other halftones
- gathered dot halftones of various screen frequencies
- 20 • continuous-tone image versus other

Spatial domain classifiers can be mapped to the wavelet domain.

Each wavelet coefficient has a support in the spatial domain. The AND, OR or majority of the spatial domain classifications for the area of support for a coefficient can be used for the classification of a coefficient. Similarly, a

- 5 wavelet domain classifier can be mapped to the spatial domain. The AND, OR or majority of the wavelet domain classifications for coefficients that have support including a particular pixel can be used for the classification of a pixel.

Many kinds of classifiers can be implemented in the wavelet domain.

- 10 Classifiers can be based on the value of a coefficients (Figure 6A) or on statistics from regions of coefficients (Figure 6B,C,D), a more thorough explanation of which are given below. Possible statistics include:

$$\text{Mean } \bar{x} = (1/n) \sum_n x \text{ and standard deviation } sd = \sqrt{\frac{1}{n} \sum_n \left(x - \bar{x} \right)^2}$$

15

- mean and first absolute moment $\frac{1}{n} \sum_n \left| x - \bar{x} \right|$
- minimum and maximum
- minimum
- maximum

A location might be classified as text (and not halftone or continuous tone image) if the mean of region was about a threshold T1 and if the variation (standard deviation or first absolute moment) was below a second threshold T2.

- 5 In one embodiment, to compute a classifier from wavelet coefficients, the local standard deviations of wavelet coefficients in different bands, levels or across bands and levels, may be computed. For example, if each level has three bands (LH, HL, and HH), then the mean for a detail coefficient is:

$$ew = \frac{d_{LH} + d_{HL} + d_{HH}}{3}$$

- 10 The standard deviation across the bands is

$$(d_{LH} - ew)^2 + (d_{HL} - ew)^2 + (d_{HH} - ew)^2.$$

- Depending on those measures, text halftone and background regions can be differentiated and a different denoising, smoothing, and sharpening parameter(s) may be applied. For example, text may be identified when the
- 15 standard deviation of coefficients at one or over several levels is small, and halftone may be identified if the standard deviation is high. This makes it possible to distinguish halftone portions from lines. Thus, different denoising, sharpening or smoothing parameters may be selected for spatial

areas (e.g., local regions in wavelet components), different bands, resolutions.

In one embodiment, a halftone-vs-line classifier is used in a wavelet-based image processing path of a copier. The difference between halftoned
 5 areas and text areas is that halftone areas consist of periodic patterns, whereas text consists of constant gray values in one direction.

A vertical line in the image produces large wavelet coefficients of the same sign along a vertical line in the HL band, whereas the coefficients next to the line are small. A horizontal line produces large wavelet coefficients of
 10 the same sign along a horizontal line in the LH band. A diagonal line produces middle sized wavelet coefficients of the same sign along a diagonal line in the HL, LH and HH band. See Figure 4A.

On the first level of decomposition, a halftoned area produces large coefficients of positive and negative sign in the HL and LH band. These
 15 coefficients are not connected, but rather "uniformly distributed". In the HH bands, a halftone area produces non-connected large size coefficients. Figure 4A illustrates the formation of wavelet coefficients of a halftone and diagonal line pattern using a 2D Haar wavelet transform.

The difference in formation of wavelet coefficients of lines and halftone areas can be captured by computing the mean and the standard deviation in a window of a special length directed in horizontal, vertical and both diagonal directions. In terms of those parameters the characterization of lines and halftone areas is shown in Table 3.

Table 3 - Characterization of lines and halftone area in directional window in the wavelet domain.

	LH: mean	LH: std	HL: mean	HL: std	HH: mean	HH: std
horizontal lines	large	small	small	small	small	small
vertical lines	small	small	large	small	small	small
diagonal lines	medium	small	medium	small	medium	small
halftone	medium	large	medium	large	medium	large

It becomes apparent that the mean computed in a horizontal or vertical window is a sufficient criterion for separating horizontal and vertical lines from halftone or diagonal lines. For distinguishing diagonal lines from halftone, the standard deviation has to be computed as an additional criterion. This classification also works on a level larger than one, if the lines have a specific thickness and the halftone a specific frequency.

In one embodiment, different classification thresholds (T_1, T_2, T_3, T_4) are chosen to classify line and halftone areas in HL/ LH and HH bands. An

```

if (mean of horizontal window centered in LH-coefficient  $d(i,j) > T_1$  AND
    std of horizontal window around coefficient  $d(i,j) < T_2$ )
then classify 3x3 window around (i,j) as being horizontal line area

10 else if (mean of vertical window centered in HL-coefficient  $d(i,j) > T_1$  AND
    std of vertical window around coefficient  $d(i,j) < T_2$  )
then classify 3x3 window around (i,j) as being vertical line area

    else if (mean of diagonal SW-NE window centered in HH-coefficient  $d(i,j) > T_3$ 
15 AND
        std of diagonal SW-NE window around coefficient  $d(i,j) < T_4$ )
then classify 3x3 window around (i,j) as being diagonal line area

    else if (mean of diagonal NW-SE window centered in HH-coefficient  $d(i,j) > T_3$ 
20 AND
        std of diagonal NW-SE window around coefficient  $d(i,j) < T_4$ )
then classify 3x3 window around (i,j) as being diagonal line area

    else
25 classify 3x3 window around (i,j) as being halftone area

```

A schematic overview of the classification based on the first level wavelet coefficients is shown in Figure 4B. This classification can work successfully in the line and halftone area.

Figure 5 illustrates 3x3 windows in the LH, HL, HH bands at level one of the wavelet decomposition. The bold coefficients are those used for the classifier.

In one embodiment, for construction of the classifier, the following 5 steps are followed.

1. Compute mean of the three bold values in each box in Figure 5, i.e.

$$\text{mean_LH} = (x_4 + x_5 + x_6)/3,$$

$$\text{mean_HL} = (x_2 + x_5 + x_8)/3,$$

$$\text{mean1_HH} = (x_7 + x_5 + x_6)/3,$$

$$\text{mean2_HH} = (x_1 + x_5 + x_9)/3.$$
2. Compute standard deviation of the three bold values in each box, i.e.

$$\text{std_LH} = \sqrt{[(x_4 - \text{mean_LH})^2 + (x_5 - \text{mean_LH})^2 + (x_6 - \text{mean_LH})^2]/3}$$

$$\text{std_HL} = \sqrt{[(x_2 - \text{mean_HL})^2 + (x_4 - \text{mean_HL})^2 + (x_8 - \text{mean_HL})^2]/3}$$

$$\text{std1_HH} = \sqrt{[(x_7 - \text{mean1_HH})^2 + (x_5 - \text{mean1_HH})^2 + (x_3 - \text{mean1_HH})^2]/3}$$

$$\text{std2_HH} = \sqrt{[(x_1 - \text{mean2_HH})^2 + (x_5 - \text{mean2_HH})^2 + (x_9 - \text{mean2_HH})^2]/3}.$$
3. Set the complete 3x3 window in the classifier image (positions of x_1, \dots, x_9) to white
 if ($\text{abs}(\text{mean_LH}) > \text{thresh}_1 \ \&\& \ \text{std_LH} < \text{thresh}_2$) OR
 if ($\text{abs}(\text{mean_HL}) > \text{thresh}_1 \ \&\& \ \text{std_HL} < \text{thresh}_2$) OR
 if ($\text{abs}(\text{mean1_HH}) > \text{thresh}_3 \ \&\& \ \text{std1_HH} < \text{thresh}_4$) OR
 if ($\text{abs}(\text{mean2_HH}) > \text{thresh}_3 \ \&\& \ \text{std2_HH} < \text{thresh}_4$).

This version of the classifier uses the mathematical definition of standard deviation. Of course, the sqrt can be eliminated by adjusting the thresholds thresh_2 and thresh_4. There may also be the possibility of substituting the squares $(.)^2$ by absolute values $|.|$. Then the thresholds

5 thresh_2 and thresh_4 will have to be chosen appropriately.

A wavelet-based classifier could also be used for nonwavelet-based operations such as halftoning or gamma correction. One example is to detect text of particular sizes in the wavelet domain and to use OCR (optical character recognition) on the text in the pixel domain, perhaps with

10 parameters chosen based on the detected font size.

Wavelet coefficients from different decomposition levels can be used in a classifier.

Classifications can also effect a single coefficient or can effect a region of coefficients.

15 In one embodiment, a wavelet coefficient is classified as being in a text region if the statistics for it or any of its eight neighbors meet thresholds for text.

Similar to the first method, in an alternative embodiment, a region around that pixel is classified instead of a single pixel. This is essentially

looking at the effect of one pixel on a region. The size of the region may depend on the scale L (e.g., the regions are selected to be of size $2^L \times 2^L$).

In yet another embodiment, for each scale $l=1..L$, a threshold T_l is selected. A pixel at position (i,j) is classified as text only if the coefficients at the corresponding positions at all scales $\ell=1..L$ are the corresponding T_ℓ threshold. Otherwise, the pixel is classified as background.

In still another embodiment, and similar to the previous method, a complete region around the located pixel is classified as text, as opposed to single pixels. Possible size of the regions include, but are not limited to: $2^L \times 2^L$.

In one embodiment, the classification of an image into text, half-tone, continuous tone (or other types) is performed in the wavelet domain or in the spatial domain by a variety of techniques.

15 Resolution Reduction and Magnification

For resampling of an image (reduction or enlargement), an interpolation filter may be used. Filters with different characteristics lead to different characteristics in the resampled image. Common problems after resampling are increased moiré artifacts, less crisp text as well as broken text

and lines. One reason for the occurrence of those artifacts is that the global filter characteristics of the interpolation filter do not match the characteristics of a local region in the image. For reduction of moiré artifacts, a filter with random elements would be well suited to destroy the periodic noise. For downsampling in text regions, a sharpening filter may be used. For upsampling of lines, a smoothing filter may be used.

Downsampling Combined With Inverse Transform

Since resampling with a linear interpolation filter is a linear operator, it can be combined with the linear wavelet transform into one operator.

Therefore, the resampling can be combined with the inverse wavelet transform into one filtering step, and resampling can be done directly on the wavelet coefficients. Since wavelet coefficients contain information on smooth and non-smooth parts of an image, different interpolation filters can be chosen depending on the absolute magnitude of wavelet coefficients or a classifier output or on other wavelet-based criteria or without information from an external classifier.

For example, for downsampling of a one-dimensional signal with a length-4 interpolation filter $[a_0, a_1, a_2, a_3]$ (e.g., Keys filter), given a Haar

wavelet decomposition, the interpolation filter can be implemented directly on the two finest level of the decomposition. Out of the redundant Haar wavelet coefficients, select the critically sampled coefficients with phase such that the support of the coefficients is in the length four window. In detail, in order to compute an interpolation point between x_{2i} and x_{2i+1} (length-4 filter applied to window x_{2i-1} to x_{2i+2}), the wavelet coefficients d_i^1, d_{i+1}^1 at level 1 and d_i^2 at level 2 and the scaling coefficient s_i^2 at scale 2 have to be used. If the inverse transform step for reconstructing the sample x_{2i} is $s_i^2 + d_i^2 + d_i^1 + d_{i+1}^1$, then the exact interpolation filtering procedure on wavelet coefficients is

$$x_{\text{int}} = (a_0 + a_1 + a_2 + a_3)s_i^2 + (a_0 + a_1 - a_2 - a_3)d_i^2 + (a_0 - a_1)d_i^1 + (a_2 - a_3)d_{i+1}^1$$

For 4-tap linear filters that preserve the DC value, i.e. $a_0 + a_1 + a_2 + a_3 = 1$, the above equation reduces to

$$x_{\text{int}} = s_i^2 + (a_0 + a_1 - a_2 - a_3)d_i^2 + (a_0 - a_1)d_i^1 + (a_2 - a_3)d_{i+1}^1$$

Different values for a_0, a_1, a_2, a_3 yield different Keys filters. One possible way of performing a signal-adaptive downsampling in the wavelet domain is, for a given a threshold T for wavelet coefficients, select a Key filter that is

suited for text if the wavelet coefficients at level two $|d_i^2|$ is larger than T and select a different Keys filter if $|d_i^2| < T$.

In one embodiment, thresholds for selecting the interpolation method or filter may vary with the amount of upsampling and for downsampling.

- 5 For example, if a particular amount of downsampling is known to be performed, an interpolation method or filter may be selected that is different than that which would be used if no such amount or a different amount of downsampling was being performed.

- 10 Similarly, the thresholds for both denoising and interpolation may vary with the amount of upsampling and/or downsampling. The thresholds for classification and interpolation may vary with the amount of upsampling and/or downsampling. Similarly, the windows upon which they operate may vary with the amount of upsampling and/or downsampling.

- 15 In one embodiment, the filter varies with the amount of up and/or downsampling, the periodicity filtered varies with the amount of up and/or

downsampling, and/or the filter support varies with the amount of up
and/or downsampling

- For a one-dimensional signal of length N , choosing matrix notation,
the linear interpolation transform is represented by matrix F_I and the
5 forward wavelet transform by the matrix W_L . The matrix representing the
combined interpolation and the inverse transform W_L^{-1} is $(F_I W_L^{-1})$.

- In general, given the interpolation filter and the wavelet transform, it
is possible to store the filter coefficients for the combined interpolation-
inverse transform in a look-up table and use that table for the filtering. If the
10 interpolation filter is of length N_F and the maximum of the length of the
wavelet transform analysis lowpass and highpass filter is N_w , then the
regular filter bank algorithm for the inverse transform can be used from
level L down to level L^* where

$$L^* = \log(\lfloor N_{F,w} \rfloor + 1) \text{ with } N_{w,F} = L \cdot 2 \left(\left\lceil \frac{(N_w - 1)}{2} \right\rceil \right) + N_F$$

For the remaining levels L^* to 1 the modified filtering procedure represented by the matrix $F_1^1 W_L^{-1}$ has to be applied. It can be also implemented at all levels $l < L^*$.

- A possible application for downsampling in a multifunction machine/copier/etc. is to store the combined interpolation-inverse wavelet transform coefficients for a fixed transform and a family of interpolation filters that covers a range of sharpening and smoothing filters. If a wavelet coefficient at level L or L^* is above a given threshold (e.g., belonging to a strong text-edge), then the coefficients for a sharpening filter + inverse transform filtering is chosen. If the coefficient is below the threshold (e.g., in background regions), then the coefficients for a smoothing filter + inverse transform filtering is chosen. For the latter one it is also possible to pick one interpolation filter randomly out of the family of interpolation filter. This introduced randomness helps to destroy periodicity in areas of moiré artifacts.

Upsampling Combined With Inverse Wavelet Transform

A similar technique can be applied for image enlargement via interpolation using a linear filter. As for resolution reduction, the length of

the interpolation filter determines the scale at which the interpolation using wavelet coefficients may be implemented. Different interpolation filters might be chosen depending on characteristics of wavelet coefficients (e.g., a smooth filter when coefficients are small, a sharpening filter when

5 coefficients are large, a filter with some random characteristics in halftone regions, etc.).

Inverse Wavelet Transform

A normal inverse transform is performed on the processed wavelet coefficients and the scaling coefficients. In one embodiment, the inverse

10 transform is performed for all L levels. In an alternative embodiment, only L-L* levels are inverted and the remaining L* levels of wavelet coefficients are used for the combined inverse-downsampling transform. If L=L*, no pure inverse is performed.

15 Gamma Correction

Gamma correction is not done directly on the wavelet coefficients and is performed in the traditional way in the pixel domain. Gamma correction may be performed on the scanned image, and before halftoning.

Halftoning

5 depending on the classifier.

10 Mask).

15 scales. Then an inverse transform is performed and a simple thresholding is

(256 x 256) because it is computational difficult to generate "colored" noise in

the spatial domain. However, in the wavelet domain adding noise of different intensities to different subbands provides an easy way to generate "blue noise" or any other desired "colored" noise. Thus, noise may be added in the wavelet domain and may be done so that different amounts of noise are added to different bands. For example, text is usually visible in HL, LH, so less noise is added there; more noise would be added in the HH.

An Exemplary Copier

Figure 7 is a block diagram of one embodiment of a digital copier.

10 Referring to Figure 7, digital copier 700 comprises a scanner 701 to scan a hard copy document to create a scanned image. The image processing that contains wavelet-based processing 702 is coupled to scanner 701 to receive the scanned image and generate a processed image. In one embodiment, image processing 702 comprises the processing path shown in Figure 2C. A
15 printer engine 703 is coupled to image processing to print the processed image.

In one embodiment, copier 700 includes an input to receive electronic versions of documents that may be sent directly to image processing 702 and then to print engine 703.

An Exemplary Computer System

An image processing path may be implemented with a computer system such as shown in Figure 8. Referring to Figure 8, computer system 5 800 may comprise an exemplary client or server computer system in which the features described herein may be implemented. Computer system 800 comprises a communication mechanism or bus 811 for communicating information, and a processor 812 coupled with bus 811 for processing information. Processor 812 includes a microprocessor, but is not limited to a 10 microprocessor, such as Pentium™, PowerPC™, Alpha™, etc.

System 800 further comprises a random access memory (RAM), or other dynamic storage device 804 (referred to as main memory) coupled to bus 811 for storing information and instructions to be executed by processor 812. Main memory 804 also may be used for storing temporary variables or 15 other intermediate information during execution of instructions by processor 812.

Computer system 800 also comprises a read only memory (ROM) and/or other static storage device 806 coupled to bus 811 for storing static information and instructions for processor 812, and a data storage device

807, such as a magnetic disk or optical disk and its corresponding disk drive. Data storage device 807 is coupled to bus 811 for storing information and instructions.

Computer system 800 may further be coupled to a display device 821,
5 such as a cathode ray tube (CRT) or liquid crystal display (LCD), coupled to bus 811 for displaying information to a computer user. An alphanumeric input device 822, including alphanumeric and other keys, may also be coupled to bus 811 for communicating information and command selections to processor 812. An additional user input device is cursor control 823, such
10 as a mouse, trackball, trackpad, stylus, or cursor direction keys, coupled to bus 811 for communicating direction information and command selections to processor 812, and for controlling cursor movement on display 821.

Another device that is coupled to bus 811 is hard copy device 824 operating as a print engine, which may be used for printing images,
15 instructions, data, or other information on a medium such as paper, film, or similar types of media. A scanner 830 is coupled to bus 811 to generate a scanned image.

Furthermore, a sound recording and playback device, such as a speaker and/or microphone may optionally be coupled to bus 811 for audio interfacing with computer system 800.

Note that any or all of the components of system 800 and associated hardware may be used in the present invention. However, it can be appreciated that other configurations of the computer system may include some or all of the devices.

Whereas many alterations and modifications of the present invention will no doubt become apparent to a person of ordinary skill in the art after having read the foregoing description, it is to be understood that any particular embodiment shown and described by way of illustration is in no way intended to be considered limiting. Therefore, references to details of various embodiments are not intended to limit the scope of the claims which in themselves recite only those features regarded as essential to the invention.

Thus, an image processing process has been described.

CLAIMS

We claim:

- 1 1. A system comprising:
 - 2 a wavelet-based image processing path to enhance an input image in
 - 3 a wavelet domain; and
 - 4 a print engine coupled to the processing path.
- 1 2. The system defined in Claim 1 wherein the image processing
 - 2 path comprises:
 - 3 a forward wavelet transform;
 - 4 one or more wavelet-based processing blocks; and
 - 5 an inverse wavelet transform.
- 1 3. The system defined in Claim 2 wherein the forward wavelet
 - 2 transform comprises a critically sampled wavelet transform.
- 1 4. The system defined in Claim 2 wherein the forward wavelet
 - 2 transform comprises an overcomplete wavelet transform.

1 5. The system defined in Claim 2 wherein the forward wavelet
2 transform comprises a Haar wavelet transform.

1 6. A system defined in Claim 2 wherein the forward wavelet
2 transform comprises a 5,3 wavelet transform.

1 7. A system defined in Claim 2 wherein the forward wavelet
2 transform comprises a 2,6 wavelet transform.

1 8. A system defined in Claim 2 wherein the forward wavelet
2 transform comprises a complex wavelet transform.

1 9. A system defined in Claim 2 wherein the forward wavelet
2 transform comprises a limited redundancy wavelet transform.

1 10. The system defined in Claim 1 wherein the image processing
2 path comprises:
3 a forward wavelet transform;

4 a denoising processing block coupled to the forward wavelet
5 transform to perform denoising based on at least one given threshold; and
6 an inverse wavelet transform.

1 11. The system defined in Claim 10 wherein the denoising
2 processing block sets coefficients below the at least one given threshold to a
3 predetermined value less than the threshold.

1 12. The system defined in Claim 11 wherein the at least one given
2 threshold is calculated based on the presence of additive Gaussian white
3 noise in an image.

1 13. The system defined in Claim 11 wherein the at least one given
2 threshold is calculated from a series of test images.

1 14. The system defined in Claim 11 wherein the at least one given
2 threshold comprises different thresholds applied to different levels of
3 decomposition.

1 15. The system defined in Claim 11 wherein the at least on given
2 threshold comprises different thresholds are applied to different bands.

1 16. The system defined in Claim 11 wherein the at least one given
2 threshold is set manually.

1 17. The system defined in Claim 11 wherein the at least one given
2 threshold is set based on the standard deviation or medium of absolute
3 values of coefficients in the region.

1 18. The system defined in Claim 17 wherein the at least one given
2 threshold is set on the standard deviation of HHI coefficients at level one.

1 19. The system defined in Claim 11 wherein the at least one given
2 threshold is set in the standard deviation or medium of absolute values of
3 HH coefficients at each level.

1 20. The system defined in Claim 11 wherein the at least one given
2 threshold is set based on the standard deviation or medium of absolute

3 values of H/HL/HH coefficients at a first level at a particular level to create
4 a band dependent threshold.

1 21. The system defined in Claim 11 wherein the at least one given
2 threshold is set based on a standard deviation or medium of absolute values
3 of LH/HL/HH coefficients at each level.

1 22. The system defined in Claim 11 wherein the at least one given
2 threshold is set manually using controls on a user interface.

1 23. The system defined in Claim 11 wherein the at least one given
2 threshold is set by computing local variances/mediums of coefficients in
3 between a band.

1 24. The system defined in Claim 11 wherein the at least one given
2 threshold is set using a classifier.

1 25. The system defined in Claim 11 wherein the denoising
2 processing block sets all coefficients below the at least one given threshold to
3 zero.

1 26. The system defined in Claim 1 wherein the image processing
2 path comprises:
3 a forward wavelet transform;
4 a sharpening or smoothing processing block coupled to the forward
5 wavelet transform to sharpen or smooth coefficients based on the magnitude
6 of individual coefficients; and
7 an inverse wavelet transform.

1 27. The system defined in Claim 26 wherein the sharpening or
2 smoothing processing block multiplies wavelet coefficients with a scale
3 dependent factor.

1 28. The system defined in Claim 27 wherein the scale-dependent
2 factor comprises:

$$3 \quad \mu_i = R \cdot 2^{\alpha_j}$$

4 where R is a renormalization factor and α is the parameter that determines
5 the degree of sharpening or smoothing.

1 29. The system defined in Claim 26 wherein the sharpening or
2 smoothing processing block normalizes coefficients after sharpening or
3 smoothing.

1 30. The system defined in Claim 28 wherein the sharpening or
2 smoothing processing block uses a scale dependent factor that is selected to
3 include normalization.

1 31. The system defined in Claim 1 wherein the image processing
2 path comprises a linear interpolation filter that is applied to wavelet
3 coefficients.

1 32. The system defined in Claim 31 wherein the image processing
2 path comprises:
3 an inverse wavelet transform to inverse transform coefficients down
4 to a predetermined level;

5 a downsampling block coupled to the inverse wavelet transform to
6 downsample wavelet coefficients.

1 33. The system defined in Claim 32 wherein the downsampling
2 block performs either a deterministic or random downsampling based on
3 coefficient size at the predetermined level.

1 34. The system defined in Claim 32 wherein the downsampling
2 block uses at least one interpolation filter based on a value of a coefficient
3 with respect to a predetermined threshold.

1 35. The system defined in Claim 34 wherein the at least one
2 interpolation filter comprises a Key's filter.

1 36. The system defined in Claim 34 wherein the downsampling
2 processing block applies a smoothing filter to wavelet coefficients that are
3 smaller than a first threshold and a sharpening filter to wavelet coefficients
4 that are larger than a second threshold.

1 37. The system defined in Claim 1 wherein the image processing
2 path comprises:
3 a forward wavelet transform;
4 a denoising processing block coupled to the forward wavelet
5 transform to perform denoising based on a given threshold;
6 a sharpening or smoothing processing block coupled to the denoising
7 processing block to sharpen or smooth coefficients based on the magnitude
8 of individual coefficients;
9 an inverse wavelet transform coupled to the sharpening or smoothing
10 processing block; and
11 a downsampling block coupled to the inverse wavelet transform to
12 downsample wavelet coefficients.

1 38. The system defined in Claim 1 further comprising an input
2 operable to receive the input image from an external source and a scanner
3 for generating the input image, wherein the input and the scanner are
4 coupled to the image processing path.

1 39. A method comprising:

2 processing an input image by enhancing the input image, including
3 applying a forward wavelet transform to create a plurality of coefficients and
4 filtering coefficients with a coefficient domain operator in a wavelet domain;
5 and
6 outputting a processed image.

1 40. The method defined in Claim 39 further comprising:
2 applying one or more wavelet-based processing blocks to coefficients
3 resulting from applying the forward wavelet transform; and
4 applying an inverse wavelet transform.

1 41. The method defined in Claim 40 wherein the forward wavelet
2 transform comprises a critically sampled wavelet transform.

1 42. The method defined in Claim 40 wherein the forward wavelet
2 transform comprises an overcomplete wavelet transform.

1 43. The method defined in Claim 40 wherein the forward wavelet
2 transform comprises a Haar wavelet transform.

1 49. The method defined in Claim 1 wherein performing denoising
2 comprises setting coefficients below the at least one given threshold to a
3 predetermined value.

1 50. The system defined in Claim 49 wherein the at least one given
2 threshold is calculated based on the presence of additive Gaussian white
3 noise in an image.

1 51. The system defined in Claim 49 wherein the at least one given
2 threshold is calculated from a series of test images.

1 52. The system defined in Claim 49 wherein the at least one given
2 threshold comprises different thresholds are applied to different levels of
3 decomposition.

1 53. The system defined in Claim 49 wherein the at least one given
2 threshold comprises different thresholds are applied to different bands.

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59. The system defined in Claim 49 wherein the at least one given threshold is set based on a standard deviation or medium of absolute values of LH/HL/HH coefficients at each level.

1 60. The system defined in Claim 49 wherein the at least one given
2 threshold is set manually using controls on a user interface.

1 61. The system defined in Claim 49 wherein the at least one given
2 threshold is set by computing local variances/medians of coefficients in
3 between a band.

1 62. The system defined in Claim 49 wherein the at least one given
2 threshold is set using a classifier.

63. The method defined in Claim 49 wherein performing
denoising comprises setting all coefficients below the at least one given
threshold to zero.

1 64.. The method defined in Claim 39 further comprising:

2 sharpening or smoothing coefficients based on the magnitude of
3 individual coefficients; and
4 applying an inverse wavelet transform on the plurality of coefficients
5 after sharpening or smoothing.

1 65. The method defined in Claim 64 wherein sharpening or
2 smoothing comprises multiplying wavelet coefficients with a scale
3 dependent factor.

1 66. The method defined in Claim 65 wherein the scale-dependent
2 factor comprises:

3
$$\mu_j = R \cdot 2^{\alpha j}$$

4 where R is a renormalization factor and α is the parameter that determines
5 the degree of sharpening or smoothing.

1 67. The method defined in Claim 64 wherein sharpening or
2 smoothing comprises normalizing coefficients.

1 73. The method defined in Claim 69 wherein downsampling
2 comprises applying a smoothing filter to wavelet coefficients that are smaller
3 than a first threshold and a sharpening filter to wavelet coefficients that are
4 larger than a second threshold.

1 74. The method defined in Claim 39 further comprising:
2 performing denoising on coefficients of the plurality of coefficients
3 based on a given threshold;
4 sharpening or smoothing coefficients of the plurality of coefficients
5 based on the magnitude of individual coefficients; and
6 applying an inverse wavelet transform to the plurality of coefficients
7 and downsampling wavelet coefficients.

1 75. A system comprising:
2 an image enhancement subsystem having a classifier to control one or
3 more of the following: denoising, sharpening, smoothing, halftoning, under
4 color removal; and
5 an output coupled to the image enhancement subsystem.

1 76. The system defined in Claim 75 wherein the image
2 enhancement subsystem operates, at least in part, in the wavelet domain.

1 77. A method comprising:
2 computing a classifier;
3 selecting different denoising thresholds for halftone and text regions
4 of an image based on the classifier.

1 78. The method defined in Claim 77 wherein computing the
2 classifier comprises computing the classifier from wavelet coefficients.

1 79. The method defined in Claim 78 wherein computing a
2 classifier comprises computing a standard deviation of wavelet coefficients
3 in different bands.

1 80. The method defined in Claim 78 wherein computing a
2 classifier comprises computing a standard deviation of wavelet coefficients
3 in different decomposition levels.

1 90. The method defined in Claim 88 wherein rescaling coefficients
2 comprises filtering LL band coefficients with a high pass filter.

1 91. The method defined in Claim 89 wherein rescaling coefficients
2 comprises filtering LL band coefficients with a low pass filter.

1 92. The method defined in Claim 84 further comprising filtering of
2 a subband at a specific level decomposition to modify the subband.

1 93. The method defined in Claim 92 further comprising filtering
2 the LL component at the largest decomposition level with a sharpening
3 filter.

1 94. The method defined in Claim 92 further comprising filtering
2 the LL component at the largest decomposition level with a smoothing filter.

1 95. The method defined in Claim 84 wherein filtering coefficients
2 comprises removing periodic patterns in a specific band by applying a filter
3 to the specific band.

1 96. The method defined in Claim 95 wherein the filter comprises a
2 band pass filter.

1 97. The method defined in Claim 95 wherein the filter comprises a
2 notch filter.

1 98. The method defined in Claim 84 wherein the period is 3.

1 99. The method defined in Claim 84 wherein the period is 5.

1 100. The method defined in Claim 84 further comprising
2 performing halftoning.

1 101. The method defined in Claim 100 wherein performing
2 halftoning comprises adding white noise with a scaled dependent variance
3 to wavelet coefficients.

1 102. The method defined in Claim 100 wherein performing
2 halftoning comprises adding white noise with a subband dependent
3 variance to wavelet coefficients.

1 103. The method defined in Claim 84 further comprising
2 resampling image data.

1 104. The method defined in Claim 103 further comprising
2 performing an inverse wavelet transform.

1 105. The method defined in Claim 104 wherein performing
2 resampling image data and performing inverse wavelet transform are
3 performed simultaneously by performing resampling directly on wavelet
4 coefficients.

1 106. The method defined in Claim 105 wherein the resampling is
2 performed using an interpolation filter.

1 111. The method defined in Claim 110 wherein performing a
2 filtering operation comprises filtering a subband at a specific level
3 decomposition to modify the single subband.

1 112. The method defined in Claim 111 wherein performing a
2 filtering operation comprises filtering the LL component at the largest
3 decomposition level with a sharpening filter.

1 113. The method defined in Claim 111 wherein performing a
2 filtering operation comprises filtering the LL component at the largest
3 decomposition level with a smoothing filter.

1 114. The method defined in Claim 110 wherein performing a
2 filtering operation comprises removing periodic patterns in a specific band
3 by applying a filter to the specific band.

1 115. The method defined in Claim 114 wherein the filter comprises
2 a band pass filter.

1 116. The method defined in Claim 114 wherein the filter comprises
2 a notch filter.

1 117. The method defined in Claim 110 wherein the period is 3.

1 118. The method defined in Claim 110 wherein the period is 5.

1 119. A copier having a wavelet-based image processing path for
2 enhancing image data.

1 120. A printer having a wavelet-based image processing path for
2 enhancing image data.

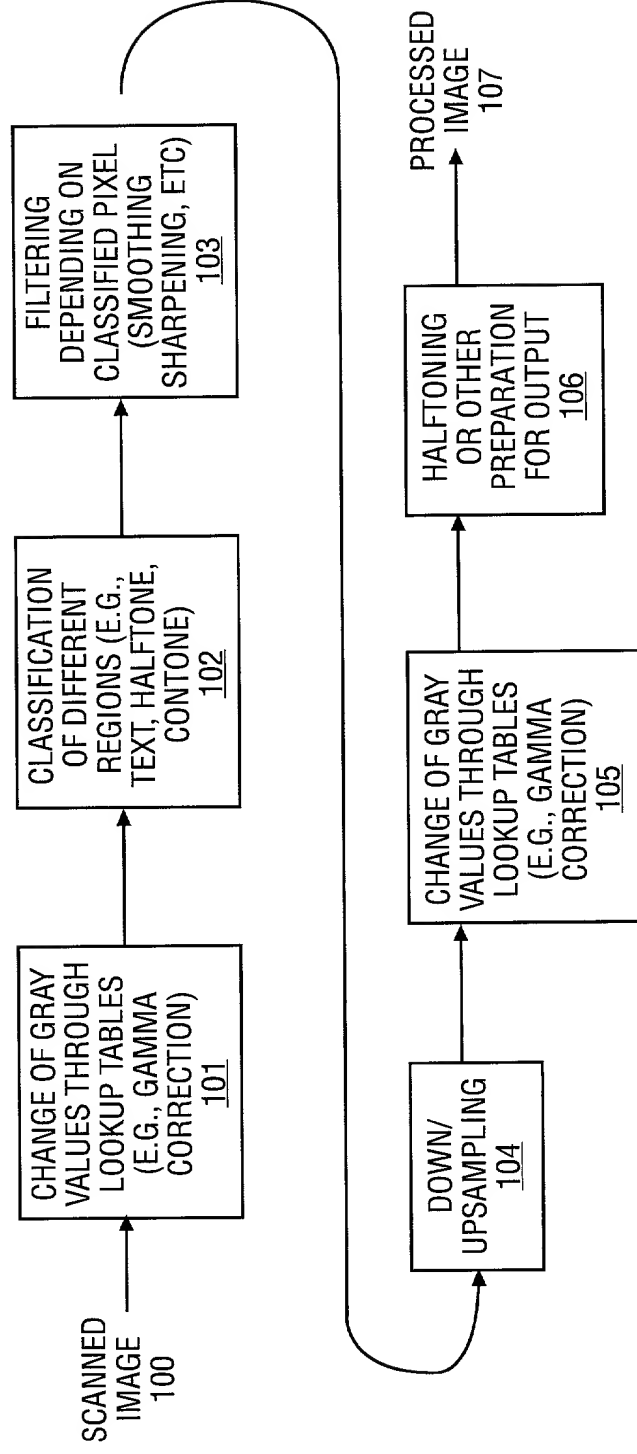


FIG. 1

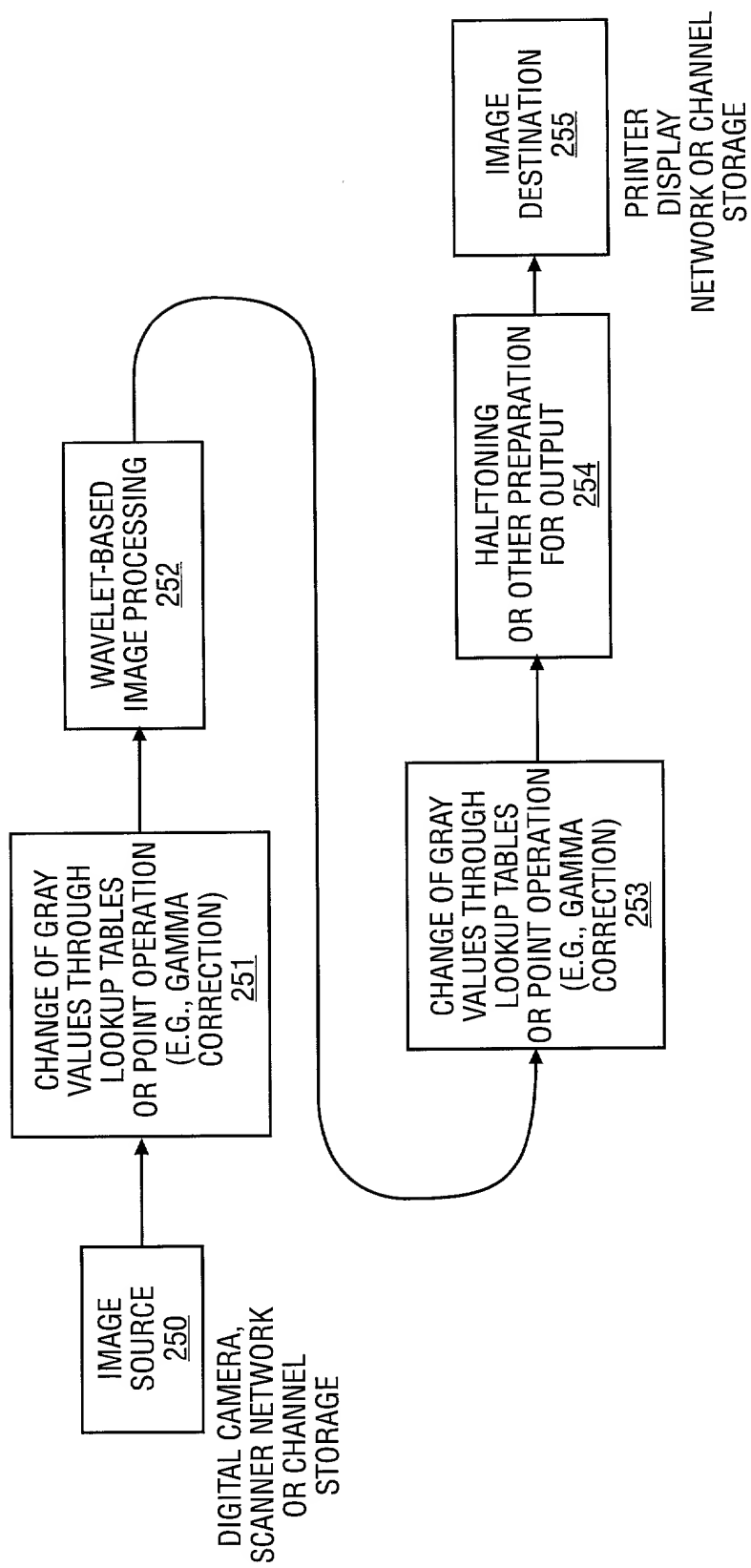
[illegible]

FIG. 2A

```
graph LR; 280[SCANNED IMAGE 280] --> 281[CHANGE OF GRAY VALUES THROUGH LOOKUP TABLES OR POINT OPERATION (E.G., GAMMA CORRECTION) 281]; 281 --> 282[WAVELET-BASED IMAGE PROCESSING 282]; 282 --> 283[CHANGE OF GRAY VALUES THROUGH LOOKUP TABLES OR POINT OPERATION (E.G., GAMMA CORRECTION) 283]; 283 --> 284[HALFTONING OR OTHER PREPARATION FOR OUTPUT 284]; 284 --> 285[PROCESSED IMAGE 285];
```

The flowchart illustrates a grayscale image processing method. It begins with a 'SCANNED IMAGE 280' which enters a block labeled 'CHANGE OF GRAY VALUES THROUGH LOOKUP TABLES OR POINT OPERATION (E.G., GAMMA CORRECTION) 281'. The output of this block goes to a block labeled 'WAVELET-BASED IMAGE PROCESSING 282'. From there, the flow continues to a block labeled 'CHANGE OF GRAY VALUES THROUGH LOOKUP TABLES OR POINT OPERATION (E.G., GAMMA CORRECTION) 283'. The output of this block then goes to a block labeled 'HALFTONING OR OTHER PREPARATION FOR OUTPUT 284'. Finally, the output of this block is the 'PROCESSED IMAGE 285'.

FIG. 2B

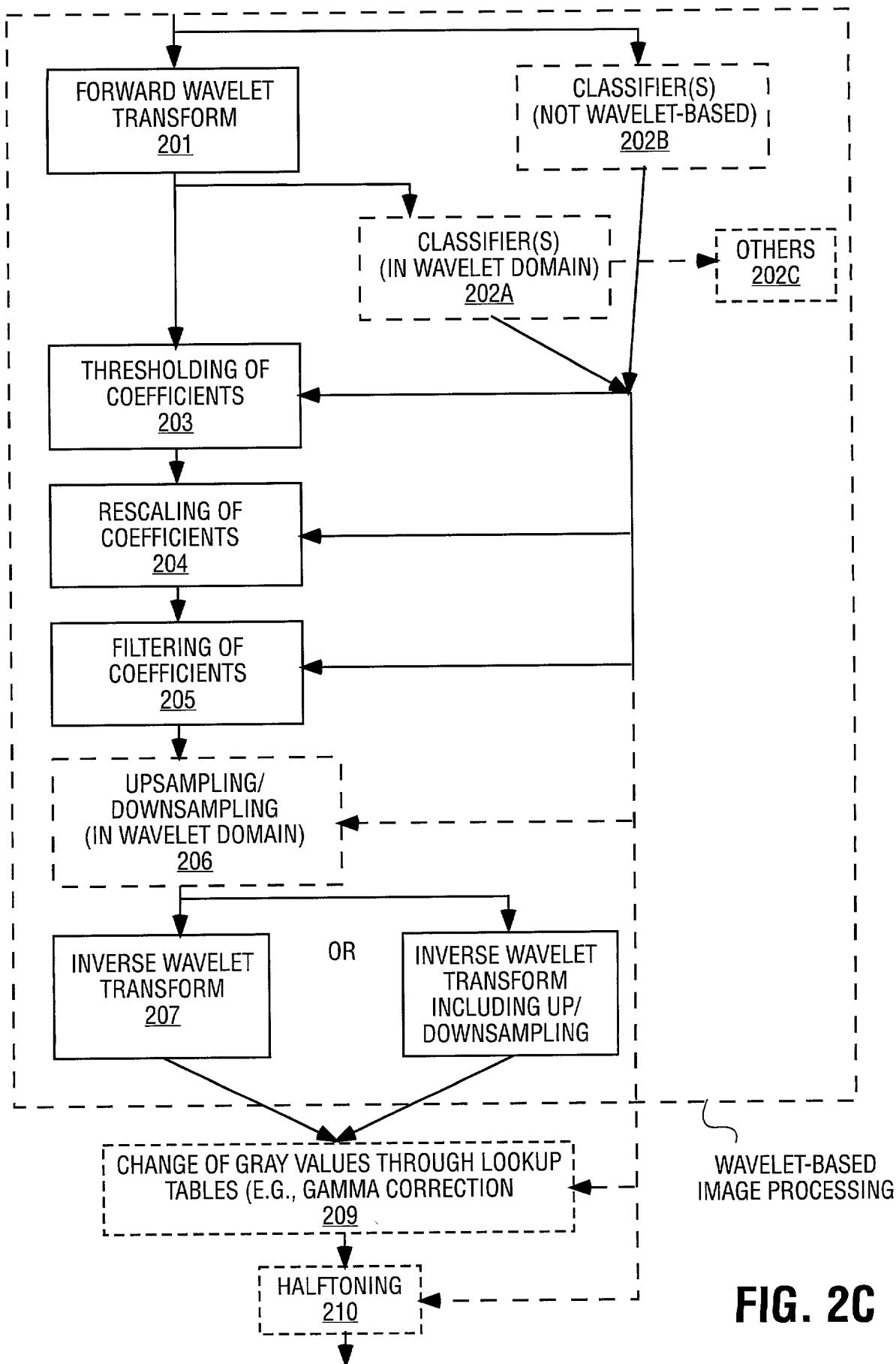


FIG. 2C

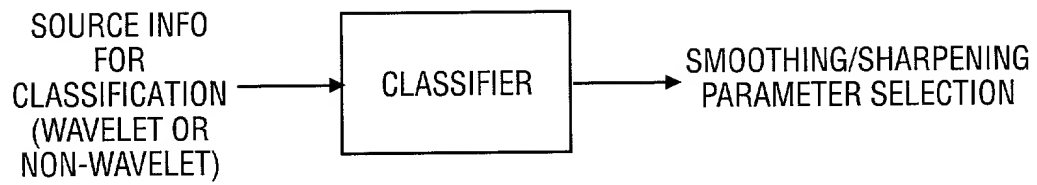


FIG. 3A

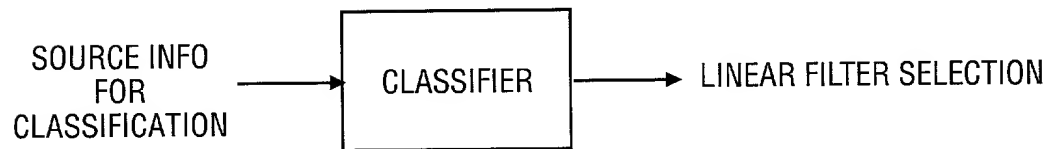


FIG. 3B

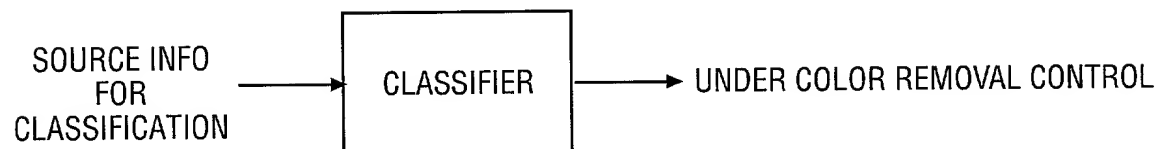


FIG. 3C

$$\begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 \end{bmatrix}$$

halftone pattern in
image

diagonal line pattern
in image

$$\begin{bmatrix} 0 & 2 & 0 & -2 & 0 & 2 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -2 & 0 & 2 & 0 & -2 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2 & 0 & -2 & 0 & 2 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & -2 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & 0 & 2 & 0 & -2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & -2 & 0 & 2 & 0 \end{bmatrix}$$

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & 0 & 2 & 0 & -2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & -2 & 0 & 2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -2 & 0 & 2 & 0 & -2 & 0 \end{bmatrix}$$

halftone pattern in HL, LH, HH band (left to right)

$$\begin{bmatrix} 1 & 1 & -1 & -1 & 0 & 1 \\ 1 & -1 & -1 & 0 & 1 & 1 \\ -1 & -1 & 0 & 1 & 1 & 0 \\ -1 & 0 & 1 & 1 & 0 & -1 \\ 0 & 1 & 1 & 0 & -1 & -1 \\ 1 & 1 & 0 & -1 & -1 & 0 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 1 & -1 & -1 & 0 & 1 \\ 1 & -1 & -1 & 0 & 1 & 1 \\ -1 & -1 & 0 & 1 & 1 & 0 \\ -1 & 0 & 1 & 1 & 0 & -1 \\ 0 & 1 & 1 & 0 & -1 & -1 \\ 1 & 1 & 0 & -1 & -1 & 0 \end{bmatrix}$$

$$\begin{bmatrix} -1 & 1 & 1 & -1 & 0 & -1 \\ 1 & 1 & -1 & 0 & -1 & 1 \\ 1 & -1 & 0 & -1 & 1 & 1 \\ -1 & 0 & -1 & 1 & 1 & -1 \\ 0 & -1 & 1 & 1 & -1 & 0 \\ -1 & 1 & 1 & -1 & 0 & -1 \end{bmatrix}$$

diagonal line pattern in HL, LH, HH band (left to right)

Figure 4A

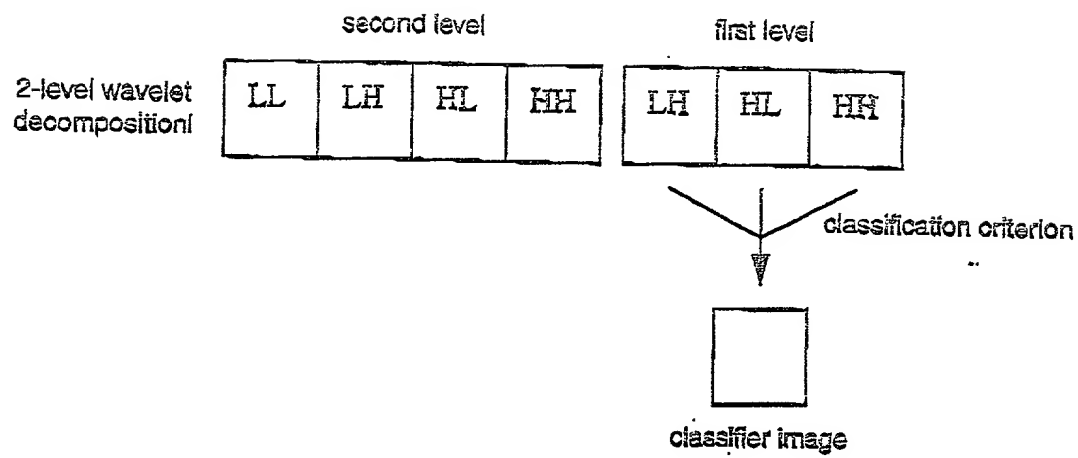


figure 4B

000000-EE889560

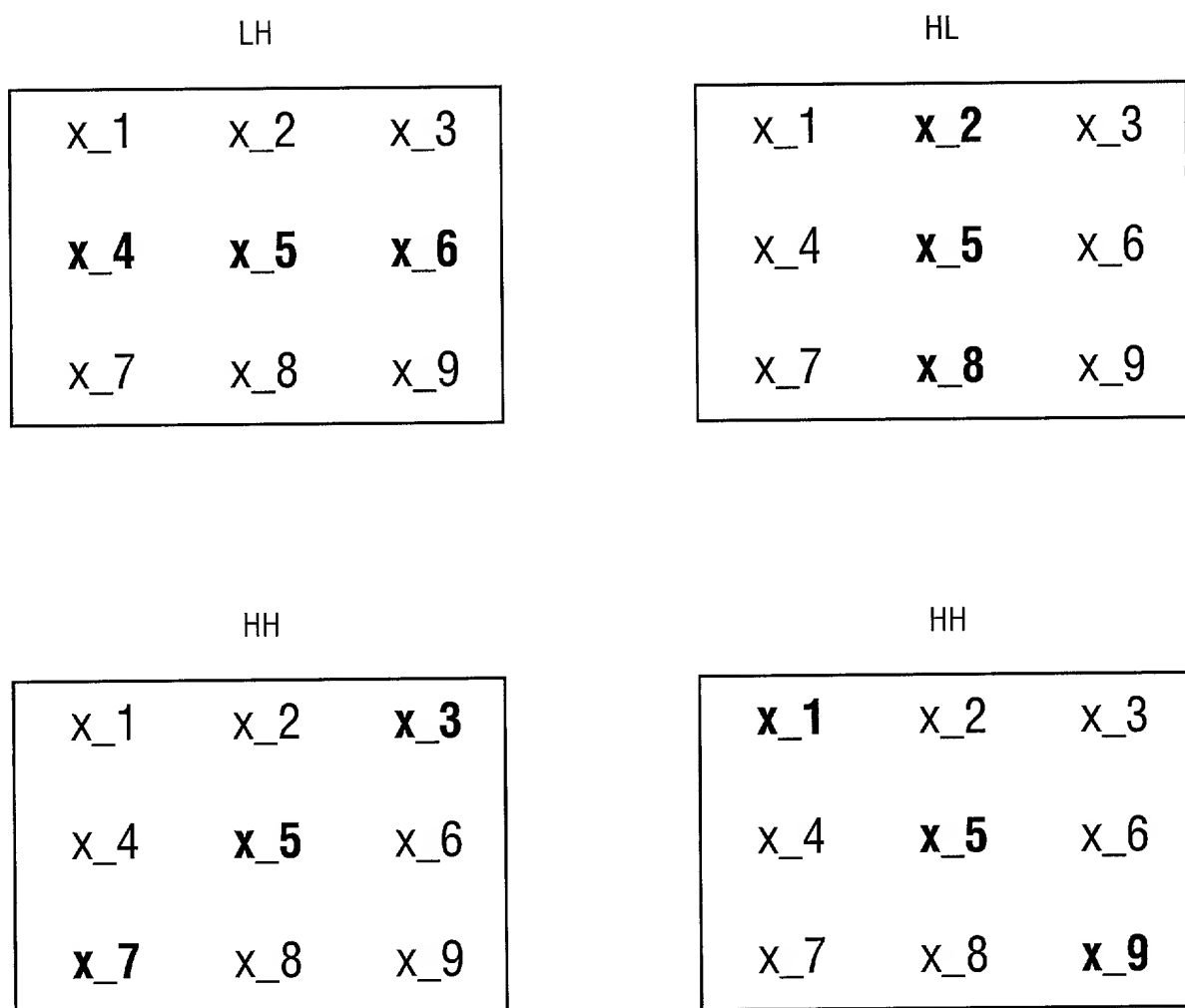

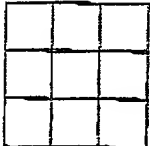
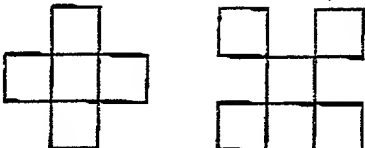


FIG. 5

(A) 

(B) 

(C) 

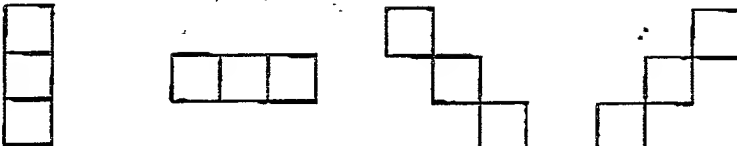
(D) 

figure 6

008060-6655560

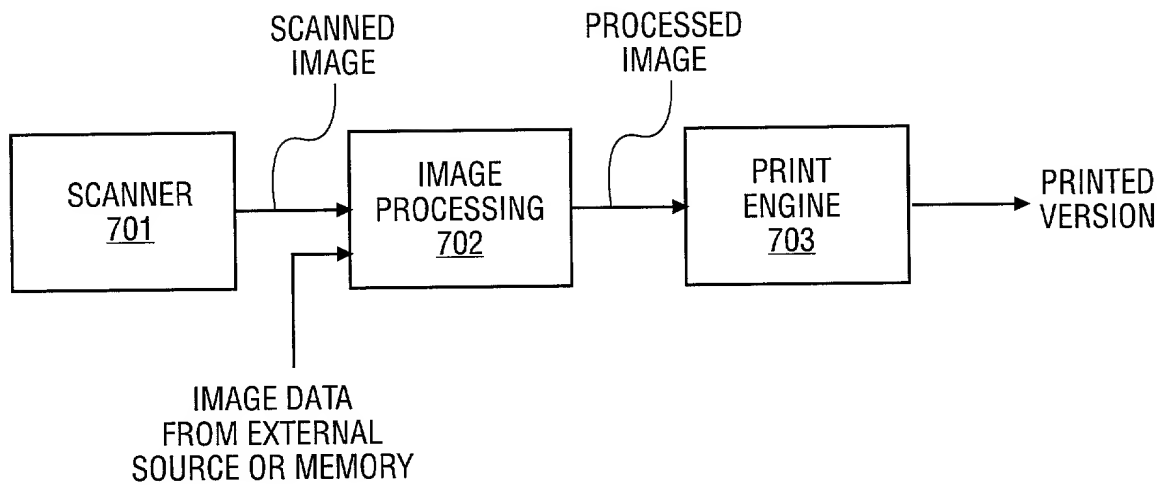


FIG. 7

800

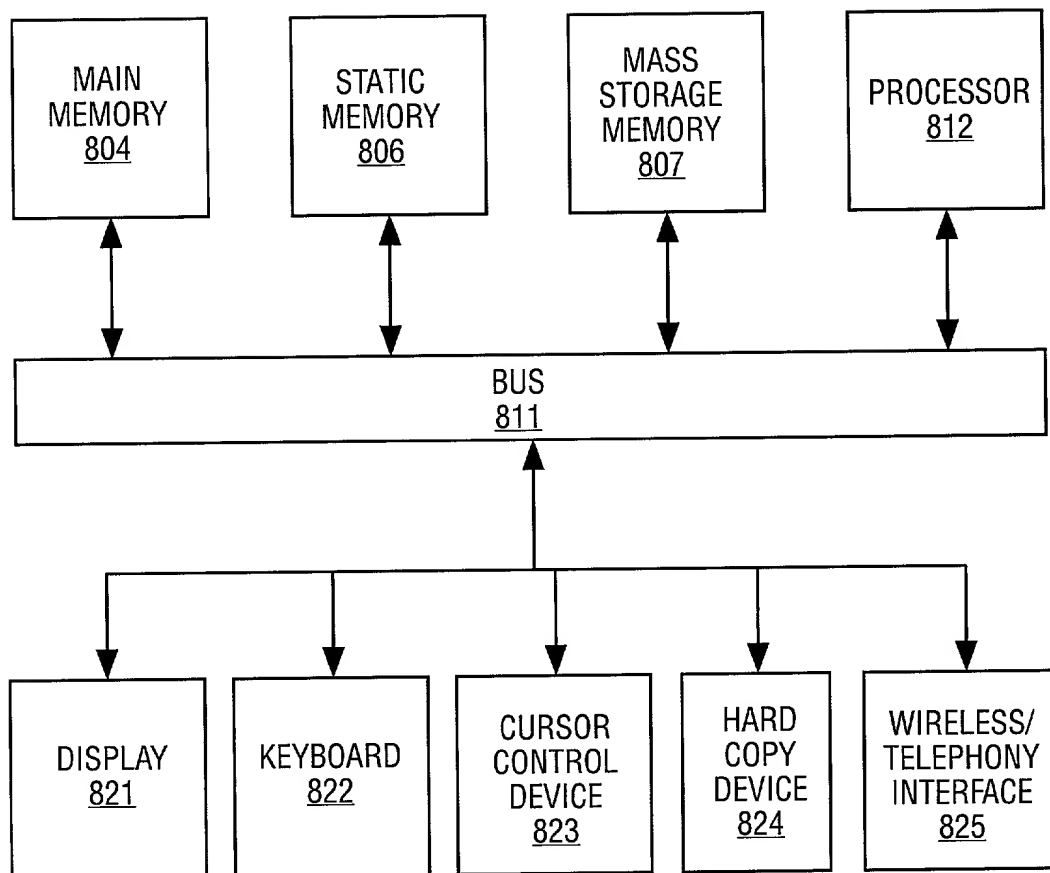


FIG. 8

DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below, next to my name.

I believe I am the original, first, and sole inventor (if only one name is listed below) or an original, first, and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

WAVELET-BASED IMAGE PROCESSING PATH

the specification of which

 X is attached hereto.
 was filed on _____ as
United States Application Number _____
or PCT International Application Number _____
and was amended on _____
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claim(s), as amended by any amendment referred to above. I do not know and do not believe that the claimed invention was ever known or used in the United States of America before my invention thereof, or patented or described in any printed publication in any country before my invention thereof or more than one year prior to this application, that the same was not in public use or on sale in the United States of America more than one year prior to this application, and that the invention has not been patented or made the subject of an inventor's certificate issued before the date of this application in any country foreign to the United States of America on an application filed by me or my legal representatives or assigns more than twelve months (for a utility patent application) or six months (for a design patent application) prior to this application.

I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d), of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)

Priority
Claimed

_____ (Number)	_____ (Country)	_____ (Day/Month/Year Filed)	<u>Yes</u>	<u>No</u>
_____ (Number)	_____ (Country)	_____ (Day/Month/Year Filed)	<u>Yes</u>	<u>No</u>
_____ (Number)	_____ (Country)	_____ (Day/Month/Year Filed)	<u>Yes</u>	<u>No</u>

I hereby claim the benefit under title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below:

_____ (Application Number)	_____ Filing Date
_____ (Application Number)	_____ Filing Date

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, Section 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

_____ (Application Number)	_____ Filing Date	_____ (Status -- patented, pending, abandoned)
_____ (Application Number)	_____ Filing Date	_____ (Status -- patented, pending, abandoned)

I hereby appoint the persons listed on Appendix A hereto (which is incorporated by reference and a part of this document) as my respective patent attorneys and patent agents, with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith.

Send correspondence to Michael J. Mallie, BLAKELY, SOKOLOFF, TAYLOR &
(Name of Attorney or Agent)
ZAFMAN LLP, 12400 Wilshire Boulevard 7th Floor, Los Angeles, California 90025 and direct
telephone calls to Michael J. Mallie, (408) 720-8300.
(Name of Attorney or Agent)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full Name of Sole/First Inventor Kathrin Berkner

Inventor's Signature _____ Date _____

Residence _____ Citizenship _____
(City, State) (Country)

Post Office Address _____

Full Name of Second/Joint Inventor Edward L. Schwartz

Inventor's Signature _____ Date _____

Residence _____ Citizenship _____
(City, State) (Country)

Post Office Address _____

Full Name of Third/Joint Inventor Michael Gormish

Inventor's Signature _____ Date _____

Residence _____ Citizenship _____
(City, State) (Country)

Post Office Address _____

Full Name of Fourth/Joint Inventor _____

Inventor's Signature _____ Date _____

Residence _____ Citizenship _____
(City, State) (Country)

Post Office Address _____

APPENDIX A

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APPENDIX B

Title 37, Code of Federal Regulations, Section 1.56 Duty to Disclose Information Material to Patentability

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclosure information exists with respect to each pending claim until the claim is cancelled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is cancelled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

- (1) Prior art cited in search reports of a foreign patent office in a counterpart application, and
 - (2) The closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.
- (b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made or record in the application, and
- (1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim; or
 - (2) It refutes, or is inconsistent with, a position the applicant takes in:
 - (i) Opposing an argument of unpatentability relied on by the Office, or
 - (ii) Asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

- (1) Each inventor named in the application;
 - (2) Each attorney or agent who prepares or prosecutes the application; and
 - (3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.
- (d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.